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DETECTION CAPABILITY OF THE KONGSBERG HGLP-SYSTEM

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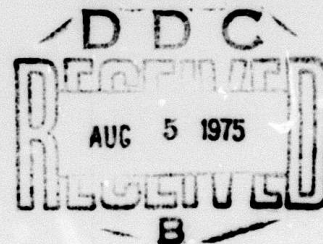
DETECTION CAPABILITY OF THE
KONGSBERG HELP-SYSTEM

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FOREWORD

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ABSTRACT

The surface wave detection capability of the Kongsberg HGLP-system has been investigated for some areas. The detection capability varies strongly from one region to another. The detection threshold for events in Central Asia is on the average at least $0.5 m_b$ units higher than for events in Iran-Afghanistan area at about the same epicentral distance.

For explosions in the Kazakh area body wave magnitude 6 is required to excite surface wave trains visible at Kongsberg.

A phase change of π has been found between the Rayleigh wave trains from two presumed underground nuclear explosions in Eastern Kazakh. The Love wave recordings from the same explosions showed unexpectedly large amplitude difference.

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INTRODUCTION

The High-Gain Long-Period (HGLP) seismograph system at Kongsberg (KON), Norway, was installed in September 1971 as part of the world-wide system of Very Long Period (VLP) instruments. Such instruments, described by Pomeroy et al. (1969), have now been installed at 10 different sites (Fig. 1) chosen to cover the main seismic zones of the world. Each site is equipped with one set of a three-component seismometer system. The seismometer output is differently filtered to give two sets of seismograms, ZHI, EHI, NHI and ZLO, ELO, NLO, and Fig. 2 shows the response curve of the vertical component (ZHI) of the KON HGLP station. The interval of maximum response, 30-50 sec, coincides with the interval where the power spectrum of the microseisms seems to have a stable minimum throughout the world (Savino et al. 1972a, Murphy et al. 1972, Sorrels et al. 1971), and the response curve is closely resembling the inverse of the average noise spectrum for periods between 10 and 100 sec (Savino et al. 1972a). This, together with a strict environmental and instrumental control, has enabled a peak magnification of about 100K.

The objective of the HGLP stations was to acquire more information on the very long periods of seismic waves (Savino et al. 1972b). Besides, one would expect these instruments, on account of the extremely high magnification, to increase the total number of detected events. Savino et al. (1972a) found that the HGLP station in Ogdensburg recorded approximately 10 times as many earthquakes as the three-component set of World-Wide Standardized Seismographs

(WWSS) at the same site. Also, Savino et al. (1972b) found that a World-Wide network of 8 HGLP stations was able to detect a total number of events considerably higher than the number of events reported in the Preliminary Determination of Epicenters (PDE) listings of the National Oceanic and Atmospheric Administration (NOAA), US.

The KON HGLP station is located close to the Norwegian Seismic Array (NORSAR), which plays a prominent part in the detection and discrimination of earthquakes and underground nuclear explosions. Since the most useful identification criterion attained so far is based on the relative difference in body wave magnitude (m_b) and surface wave magnitude (M_s) for earthquakes and explosions (Evernden 1969, Savino et al. 1971), a successful identification is often dependent on the recording of the surface waves. Savino et al. (1971) defined the regional discrimination threshold as the smallest m_b for which measurable surface waves from all earthquakes in a given area are recorded. Thus, the recording of surface waves is essential in order to lower the threshold value, and in this respect the KON HGLP station (and other HGLP stations) might be helpful.

The purpose of this investigation has been to study the detection capability of the KON HGLP system for events from different regions. In connection with the identification problem, the Central Asian area, including the Kazakhstan and Western Russia test sites for underground explosions, is of special interest.

REGIONAL DETECTABILITY OF THE KONGSBERG HGLP-STATION.

The events reported in the PDE listings of NOAA have been used as a basis of comparison in the measurement of the regional detection capability of the Kongsberg HGLP station. All events in the time period September 72 - May 74 from selected epicenter regions have been picked from the PDE lists, and the seismograms from Kongsberg have been thoroughly searched for these events. Using the numbering system of Flinn and Engdahl (1965) for geographical regions, the selected epicenter areas are: 321-406, 633-658 and 713-726. Fig. 3 shows the obtained epicenter map. Events occurring in time periods when the Kongsberg HGLP was not operating, and events which we were not able to separate from other interfering events, have been removed from the map. Events detected by Kongsberg HGLP system are marked with a square, while the crosses denote the undetected events.

The detectability of Kongsberg HGLP system for 5 epicenter regions is shown in the form of histograms in Figs. 4-6. The detectability as compared to NOAA is varying. The histograms for the Arctic zone and the Atlantic ocean (Fig. 4) and the Iran-Afghanistan region (Fig. 5) show that almost all events reported by NOAA from these regions have been detected by the Kongsberg station, so no exact detection limit can be established from this data set.

The histogram from the Mediterranean area (Fig. 5) shows a greater percentage of undetected events. This seems partly to be caused by a better NOAA detectability for this area, more low magnitude events being reported from this region than from the others, but also by a somewhat poorer

detection capability for Kongsberg HGLP system. Many events with magnitude up to 4.3 are not detected.

The last region to be discussed is the Hindu Kush and Pamir area, and the histogram in Fig. 6 (top) shows that merely events of magnitude $m_b > ca5$ are recorded at Kongsberg.

The result for this region should be compared with the histograms from the Iran-Afghanistan area (Fig. 5) since these two regions are located near each other and are at about the same distance from KON. The evident difference in the sets of events from the two regions lies in the difference in focal depths. Iran-Afghanistan events are normally shallow while many Hindu Kush events are deep and not likely to generate strong surface waves. However, this can not fully explain the many undetected events. Fig. 6 (bottom) shows a histogram of the shallow ($h < 100$ km) Hindu Kush and Pamir events, and as can be seen this histogram is not significantly different from that of all events. It must be concluded that the detectability of the KON HGLP station for events from this area is poor.

The use of the NOAA reported events as a measure of seismicity is not quite satisfactory. The WWSS network, on which the NOAA reports are based, also, of course, has its detection limits, and these we do not know. The histograms (Figs. 4-6) show that for each of the epicenter regions the distributions of the events with magnitude are different, indicating that the detectability of the WWSS network is also varying from region to region. Therefore, we have not tried to establish any absolute detection limits for the KON HGLP station.

The encircled events on Fig. 3 are presumed explosions in Kazakhstan and Western Russia. All explosions in this area in the time period September 72 - May 74 are listed in Table 1. Only two of these, both from Eastern Kazakhstan, have been recorded at KON, while several explosions with $m_b > 5.5$ have not been detected. There are no earthquakes to compare with from the explosion area, so it is hard to tell whether this poor detectability is tied to explosion source characteristics alone or if it would be valid for other sources in the same area as well. However, the seismic active area closest to the explosion areas is the Hindu Kush and Pamir region, and there might be a common reason for the lack of surface waves from earthquakes in this region and from explosions in Central Asia. Wave trains from earthquakes and explosions will be discussed later in this report.

The KON HGLP station has been observed to record many events not reported in any seismic bulletin. No systematic investigation in order to map the amount and epicenter distribution of these events has yet been performed. However, from the dispersion characteristics of the wave trains, we conclude that many of these unidentified events occur on or near the Mid-Atlantic Ridge. In Fig. 7 we have shown as an example the ZHI-recording of an event, which has not been reported by other agencies.

SPECTRAL COMPOSITION OF EVENTS FROM DIFFERENT REGIONS.

Events from different regions have been selected for frequency analysis. Normalized amplitude spectra of wave trains from some events are shown in Figs. 8-13. The spectra are not corrected for instrument response, and no smoothing has been applied.

The spectral composition of surface waves from events in Central Asia, i.e. the earthquakes in Sinkiang and Tadzhik, and the explosions in Kazakh, seems to be different from the spectral composition of events from other regions. This is most pronounced for Rayleigh waves; the majority of the Central Asian events have relatively more high frequency energy than events in other regions. A significant part of the energy in the Rayleigh wave trains from Central Asia is distributed at frequencies above 0.05 Hz (where the instrument response (Fig. 2) is rapidly decreasing), and this is the case for both earthquakes and explosions (Figs. 9, 10 and 11).

However, there are examples of events which do not fit quite well into this picture (Fig. 8).

Since the spectra presented are amplitude normalized they do not clearly point out whether the majority of the Central Asian events are characterized by enrichment of high frequency Rayleigh wave energy, or simply by the absence of low frequency energy. However, one notices that when Love waves are present, their energy distribution does not vary significantly from one region to another. (Figs. 9, 10 and 12).

Of the two Tadzhik earthquakes (Figs. 8 and 9) only one has well developed Love waves. The same is true for the two Kazakh explosions (Fig. 18) and in both cases the Love waves have an energy distribution not very different from that of events from other regions (Figs. 11 and 12).

The HGLP-instruments were designed to have the peak response where the earth noise has its minimum. The earth noise is varying both with the time and as a function of frequency and sometimes the changes are very rapid. (Rygg and Bruland, 1974).

To get an estimate of the average noise situation we have selected 12 minutes long samples from each seismogram and prepared weekly and monthly power spectral density averages. By such a procedure one may of course average out significant details, but due care has been taken in selecting representative samples.

In Fig. 14 the ZHI average noise power spectrum for one winter month is shown together with the power spectrum of a Kazakh explosion. It is evident that under such (extreme) noise conditions the lower frequency surface waves (0.02 - 0.05 Hz) are as likely to be detected as the Continental Airy phase, even if the latter arrives with greater energy concentration (in time).

SURFACE WAVES FROM KAZAKH EXPLOSIONS

Two events in Table I are of particular interest and have been subject to some detailed investigations. Apart from being the only explosions in Eastern Kazakh that have been detected by the Kongsberg system, the surface wave trains of these events show some surprising discrepancies.

The two events are the Kazakh explosions on 10 December 1972, 04:27:08.4 (NOAA) and on 23 July 1973, 01:22:57.8 (NOAA). Actually, on 10 December 1972 2 explosions are reported (04:26:57.6 and 04:27:08.4), but according to the statistics given earlier in this paper (Table 1) one would not expect visible surface wave recordings at Kongsberg from the first of these events. ($m_b = 5.7$ NOAA, $m_b = 5.5$ NORSAR). Furthermore, the surface wave train looks like it stems from one event only; (Fig. 16) with no amplitude modulation which is characteristic for added dispersive wave trains from multiple events.

We have tried to resolve the complete signal into a spike series convolved with a characteristic signal by using a complex cepstrum technique (Linville 1971, Tsai 1972), but with no success. However, it should be pointed out that the composite wave train from two events separated in time by about 10 seconds would result in a modulation of the spectrum with a "hole" at around 0.05 Hz, and this appears to be the case (Fig. 11).

Still, we do believe that the surface wave train recording of 10 December 1972 stems from the last of the two explosions only, and the most conclusive evidence can be found from the travel times. From this area the arrival times of the surface

waves can be very accurately determined, and even small deviations will be discovered when using both the NORSAR and the Kongsberg recordings.

In the following we have used the origin times and the epicenter coordinates given by NOAA. According to these data the surface wave trains should be in phase and in the same positions at 10 December, 04:44:00 and at 23 July, 01:39:50, if the source mechanisms were identical. This is the case for the Love waves with the accuracy we are able to measure. This is demonstrated on Fig. 17, where we have used the NORSAR recordings because of the very poorly developed long period Love waves at Kongsberg of the explosion 23 July 1973 (Fig. 18).

However, if we look to the Rayleigh wave recordings, and put the traces on top of each other at the expected arrival times, we find that they are 180° out of phase (Fig. 16). Using the Kongsberg recordings it is not possible to check small deviations in arrival times, but the wave trains match well when the polarity of one of them is reversed. This polarity change can, if it is real, only be caused by differences in the sources. (It should be added here that the polarity of the instruments has been checked using known events with well defined long period P-wave signals).

The Kongsberg system is a broad band system, and as such it permits comparison of very long fractions of the wave trains. However, for the USSR explosions also the NORSAR long period system is very efficient since the response is peaked around the frequency of the continental Airy phase. Very often, therefore, one experiences that this system detects the USSR high frequency events quite well.

The surface waves of the two explosions mentioned have both been detected by the NORSAR LP-system, and when we put the corresponding LPZ-traces on top of each other as we did with the Kongsberg recordings, we still get a poor match (Fig. 19). Note that the time scale is different, so what is shown on Fig. 19 is essentially the continental Airy phase. On reversing the polarity of one of the sets of traces we again get an excellent fit. Actually, the fit is so good that details of the wave trains which at a first glance would be classified as microseismic noise must be interpreted as part of the Rayleigh wave train.

However, to get this fit we had to displace one of the sets of traces by some 5 seconds relative to the expected arrival time. More precisely; using the NORSAR recordings and reversing the polarity, the continental Airy group of the 10 December 1972 explosion seems to be delayed by 5 seconds.

This is the event for which we discussed the possibility of a composite wave train above. However, since the smallest explosion occurred about 10 sec before the main event this finding corroborates our conclusion that the Rayleigh wave train recorded was excited by the largest event only. At this point we also would like to repeat that the Love wave trains were in phase and arrived at the expected arrival times (Cfr. Fig. 17).

The Rayleigh wave phase change that has been documented by comparing the vertical components is also demonstrated in Fig. 20, where corresponding NORSAR LPEW-recordings from the two Kazakh explosions have been put on top of each other after changing the polarity of one of them and adjusting to get the best fit.

Again we notice the excellent fit in the details of the Rayleigh wave trains and as before the time adjustment necessary was about 5 seconds.

Finally, we return to the Love waves excited by these two explosions. The Kongsberg recordings are not scaled, so the difference in amplitudes shown is real. It is surprising that the two explosions with nearly identical Rayleigh waves have so different Love wave amplitudes (Fig. 18). Also, we find from the NORSAR recordings that the explosion of 23 July 1973 has a Love wave train with long coda contrasting to the other explosion (Figs. 17 and 18).

In order to check if this complex coda might be due to multipathing we have computed the wave number spectra for the entire array signal field for two consecutive time intervals; 01:42:00-01:45:00 and 01:45:00-01:48:00.

However, the azimuthal variations that could be found were smaller than the resolution power of the method, so there was nothing in these computations that led us to believe that different directions of approach could cause the complex Love wave coda. An example of the wave number spectra is given in Fig. 21, and as we see the concentration of the source and the signal to noise ratio are the only significant differences between the two time intervals.

CONCLUSIONS

The detection capability of the Kongsberg HGLP station is found to be strongly dependent on epicentral region. The Kongsberg station detects most of the events given in the PDE listings of NOAA from the Arctic Zone, the North Atlantic Ocean and the Iran-Afghanistan area. The detection threshold for these regions is $m_b = 4.3 - 4.4$ (which also seems to be the detection limit of NOAA for these regions). It is also observed that many events, which have not been reported by NOAA, have been recorded by Kongsberg. The epicenters of these events are believed to be located on or near the Mid-Atlantic Ridge.

Contrasting to this, the Central Asian events are poorly detected by the HGLP station (m_b threshold about 5.0). Surface waves from explosions in this region, i.e. in Kazakh and Western Russia, are rarely seen at Kongsberg. The lack of long period surface waves from earthquakes in Central Asia can not be explained by the deeper focal depths alone.

The energy of Rayleigh waves from Central Asian events including the explosions in Kazakh, seems to be distributed on higher frequencies than Rayleigh waves from other areas.

We have demonstrated some surprising differences between the long period recordings of two Kazakh explosions. The associated problems - the possible explanations of differences in source locations and time functions have only loosely been approached, and will be covered in a later report. At this stage, therefore, we content ourselves with summarizing the essential findings:

1. The phase change of the Rayleigh wave trains as demonstrated by the Kongsberg Z and the NORSAR Z and EW components.
2. The time displacement of 5 seconds necessary to get the NORSAR Rayleigh wave recordings cover each other, contrasting with the Love wave recordings where no time adjustments were necessary.
3. The large difference between the two events in excitation of long period Love waves.
4. The difference between the two events in the coda level of the Love wave trains at NORSAR.

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Table 1

Presumed explosions in Kazakhstan and Western Russia.

Date	Explosion time	Latitude	Longitude	m _b (NOAA)	m _b (NORSAR)	Kongsberg HGLP
2 SEP 72	08.56.57.6	49.957N	77.726E	5.1	4.5	Not detected
21 SEP 72	08.59.57.0	52.1 N	52.0 E	5.2		Not detected
3 OCT 72	08.59.57.8	46.848N	45.010E	5.8	5.7	Not detected
2 NOV 72	01.26.57.6	49.913N	72.837E	6.2	5.9	Not detected
24 NOV 72	09.00.08.0	52.779N	51.067E	4.7	4.5	Not detected
24 NOV 72	09.59.57.8	51.843N	64.152E	5.2	4.7	Data missing
10 DEC 72	04.26.57.7	49.847N	78.099E	5.7	5.5	Not detected (?)
10 DEC 72	04.27.08.4	50.114N	78.808E		5.9	Detected
28 DEC 72	04.26.57	49.6 N	79.0 E		4.2	Interfering event
16 FEB 73	05.02.57.7	49.8 N	78.2 E	5.6	5.4	Not detected
19 APR 73	04.32.57.6	50.006N	77.725E	5.4		Not detected
23 JUL 73	01.22.57.8	49.986N	78.853E	6.3	6.0	Detected
15 AUG 73	01.59.57.8	42.711N	67.410E	5.3	5.4	Not detected
28 AUG 73	02.59.57.6	50.550N	68.395E	5.3	5.1	Not detected
19 SEP 73	02.59.57.2	45.635N	67.850E	5.2	5.0	Not detected
30 SEP 73	04.59.57.5	51.608N	54.582E	5.2	5.2	Not detected
26 OCT 73	04.26.57.7	49.765N	78.196E	5.3	5.2	Not detected
26 OCT 73	05.59.57.6	53.656N	55.375E	4.8	4.8	Not detected
14 DEC 73	07.46.57.0	50.036N	79.011E	6.0	5.8	Data missing
20 MAR 74	11.00.08	59.0 N	47.5 E		3.5	Not detected
25 MAR 74	06.18.09	51.2 N	78.8 E		3.8	Not detected
16 MAY 74	03.02.57.3	49.743N	78.150E	5.3	5.3	Not detected
31 MAY 74	03.26.57.4	49.952N	78.844E	5.9	6.1	Interfering event
31 MAY 74	09.25.06	52.6 N	74.5 E		3.6	Not detected

HGLP STATIONS

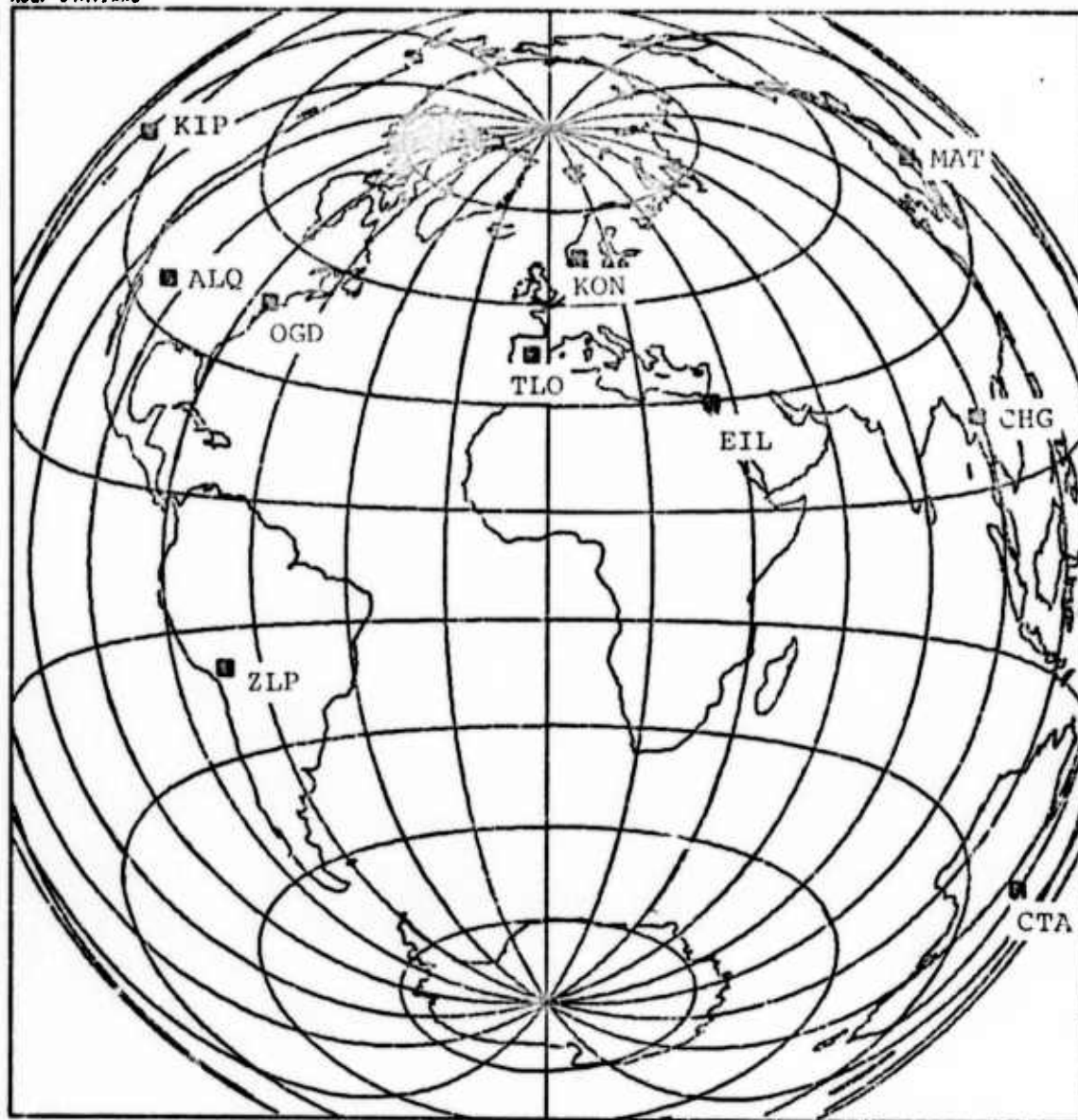
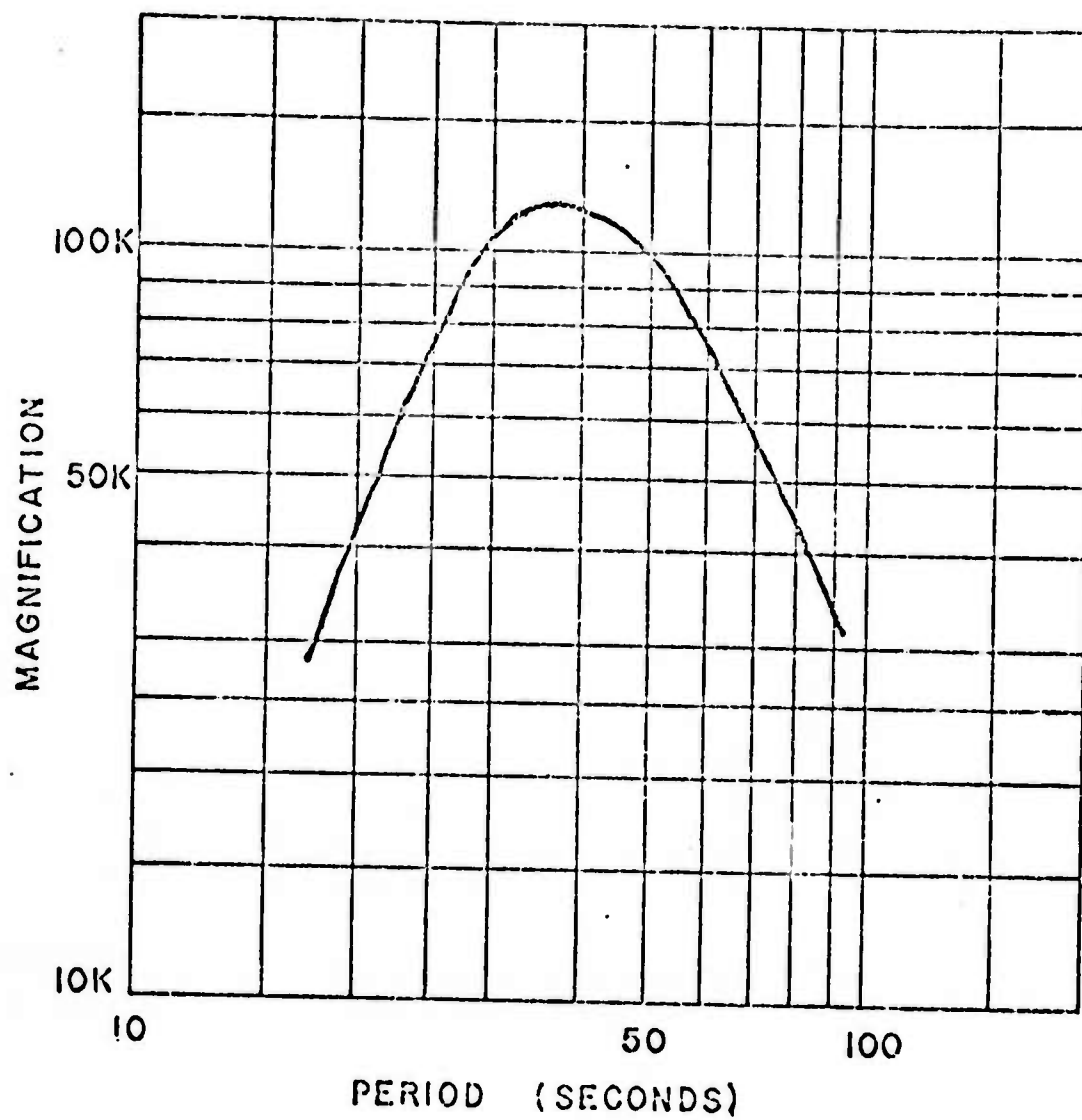


Fig. 1. The world-wide network of HGLP stations.



VERTICAL HIGH-GAIN COMPONENT ZHI

Fig. 2. Response curve for the KON HGLP vertical instrument

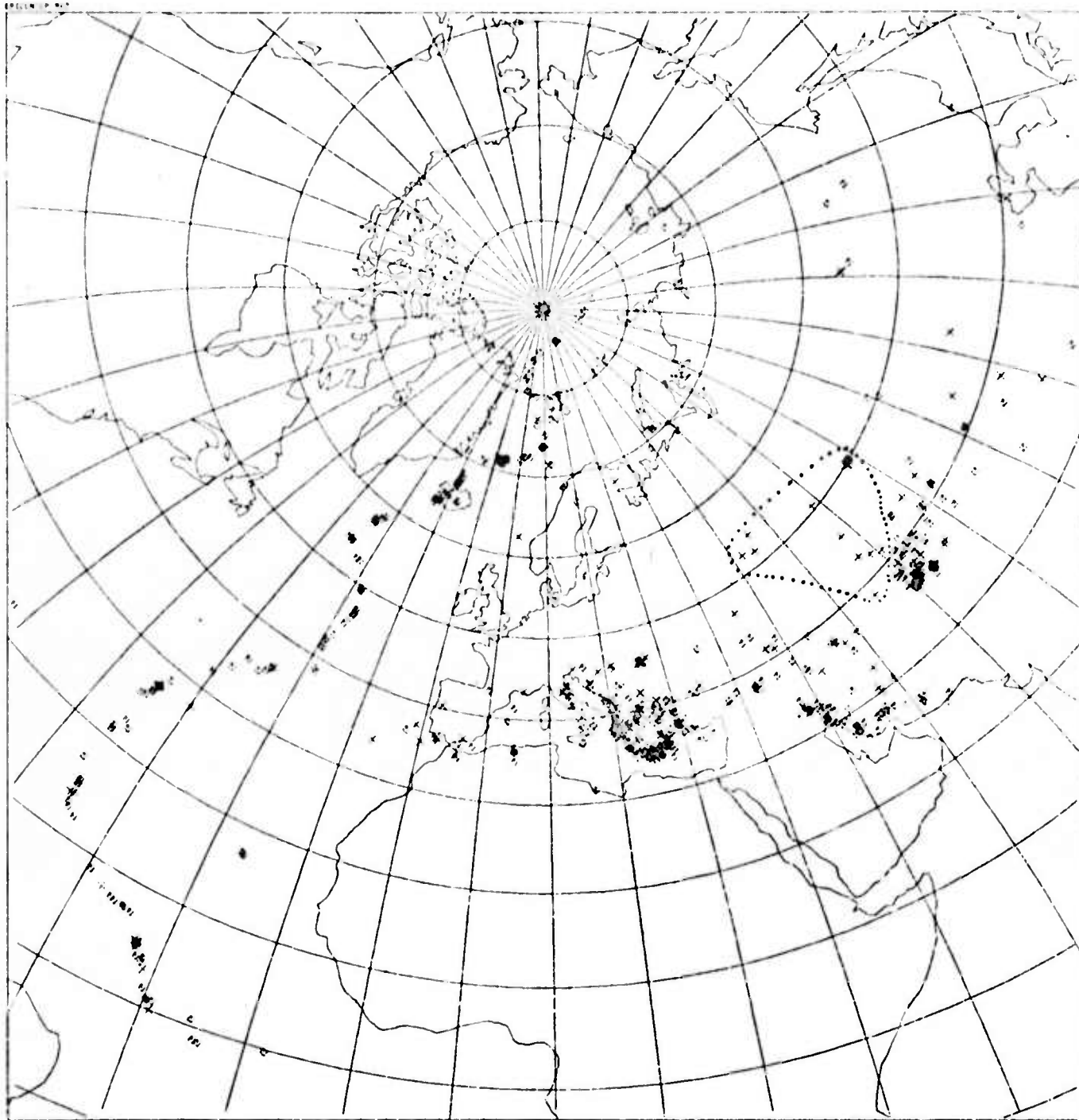


Fig. 3. Epicenter map showing events reported by NOAA from the time period September 72 - May 74. Events also detected by the KON HGLP system are marked with squares, while crosses identify undetected events.

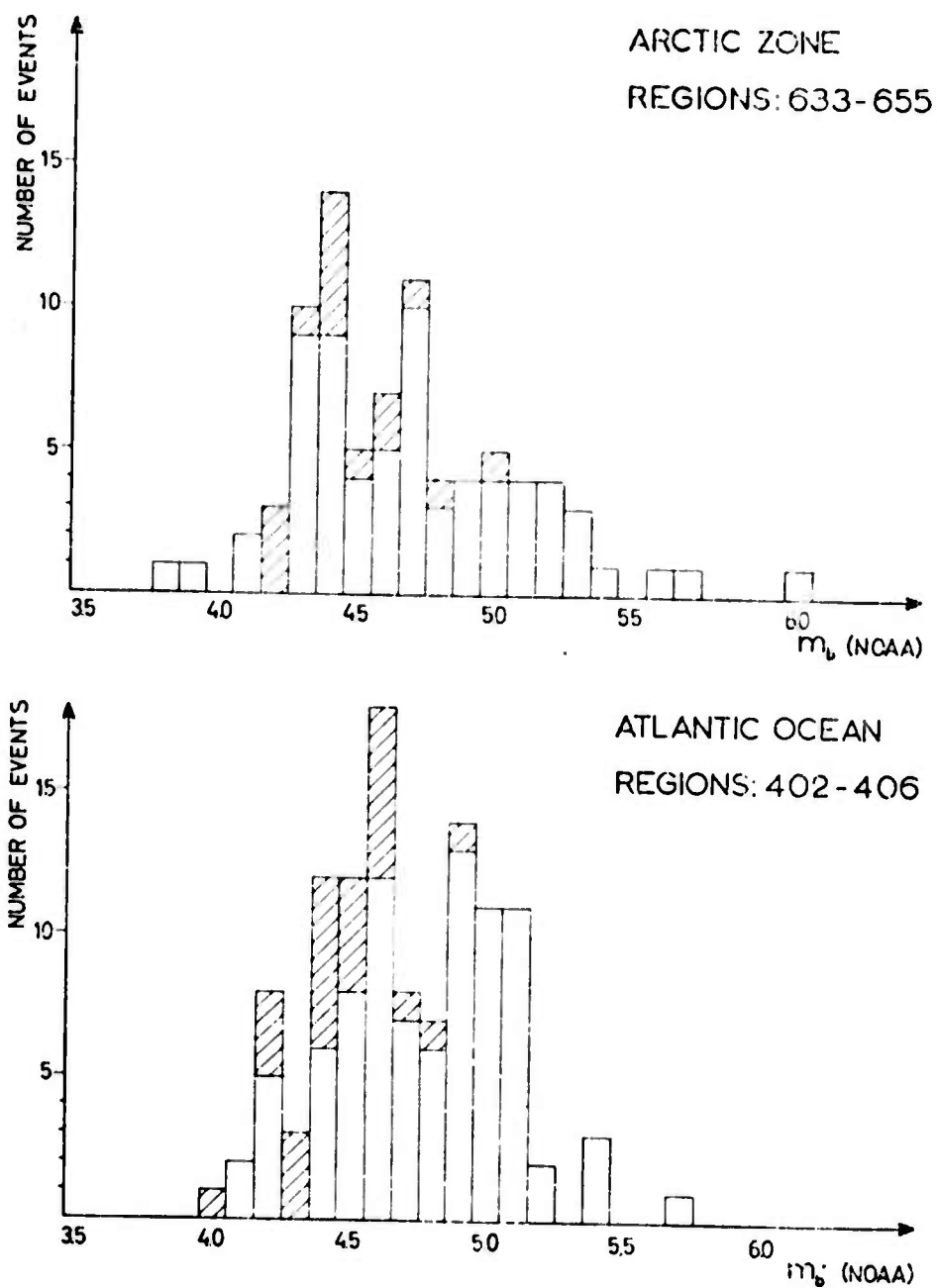


Fig. 4. Histograms showing the detection capability of the KON HGLP system for events from The Arctic Zone and The Atlantic Ocean. Hatched areas represent undetected events.

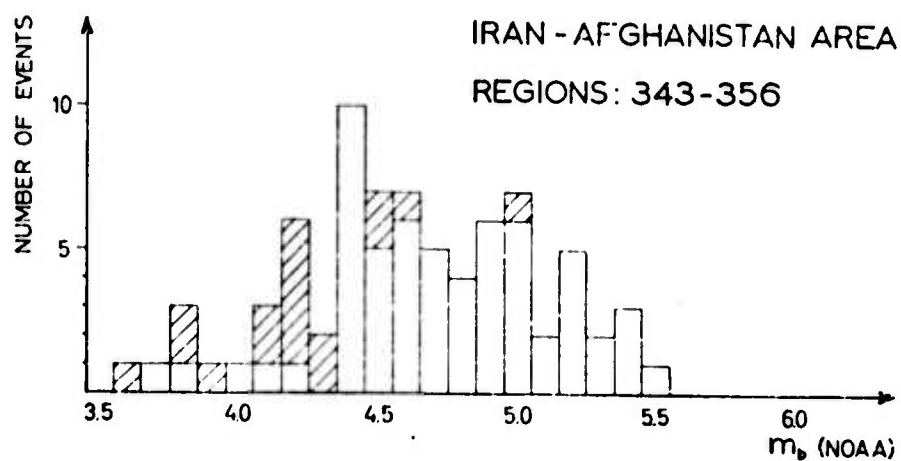
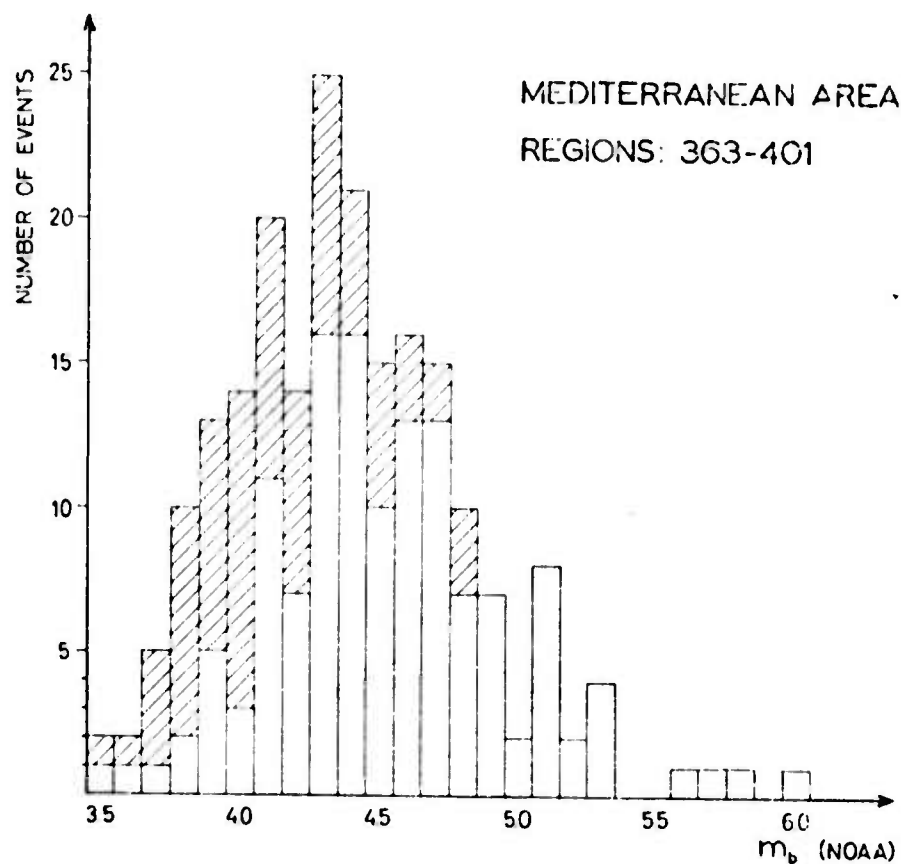


Fig. 5. Histograms showing the detection capability of the KON HGLP system for events from the Mediterranean Area and the Iran-Afghanistan Area. Hatched areas represent undetected events.

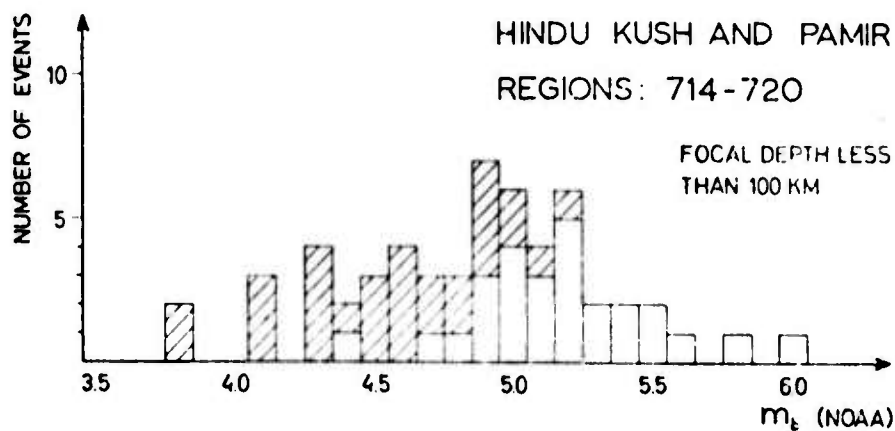
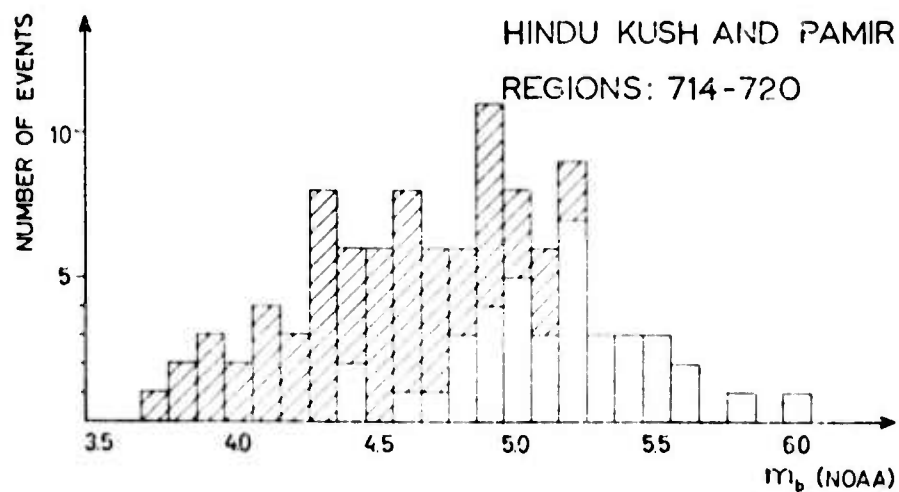


Fig. 6. Histograms showing the detection capability of the KON HGLP system for events from the Hindu Kush and Pamir region. Shallow events ($h < 100$ km) are shown in the bottom histogram. Hatched areas represent undetected events.

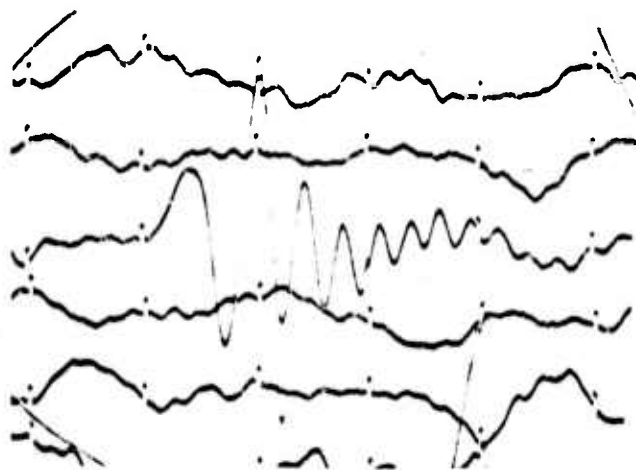


Fig. 7. Kongsberg ZHI-recording 20 August 1973, 20:07:00 - 20:12:00. This event has not been reported by any other agency.

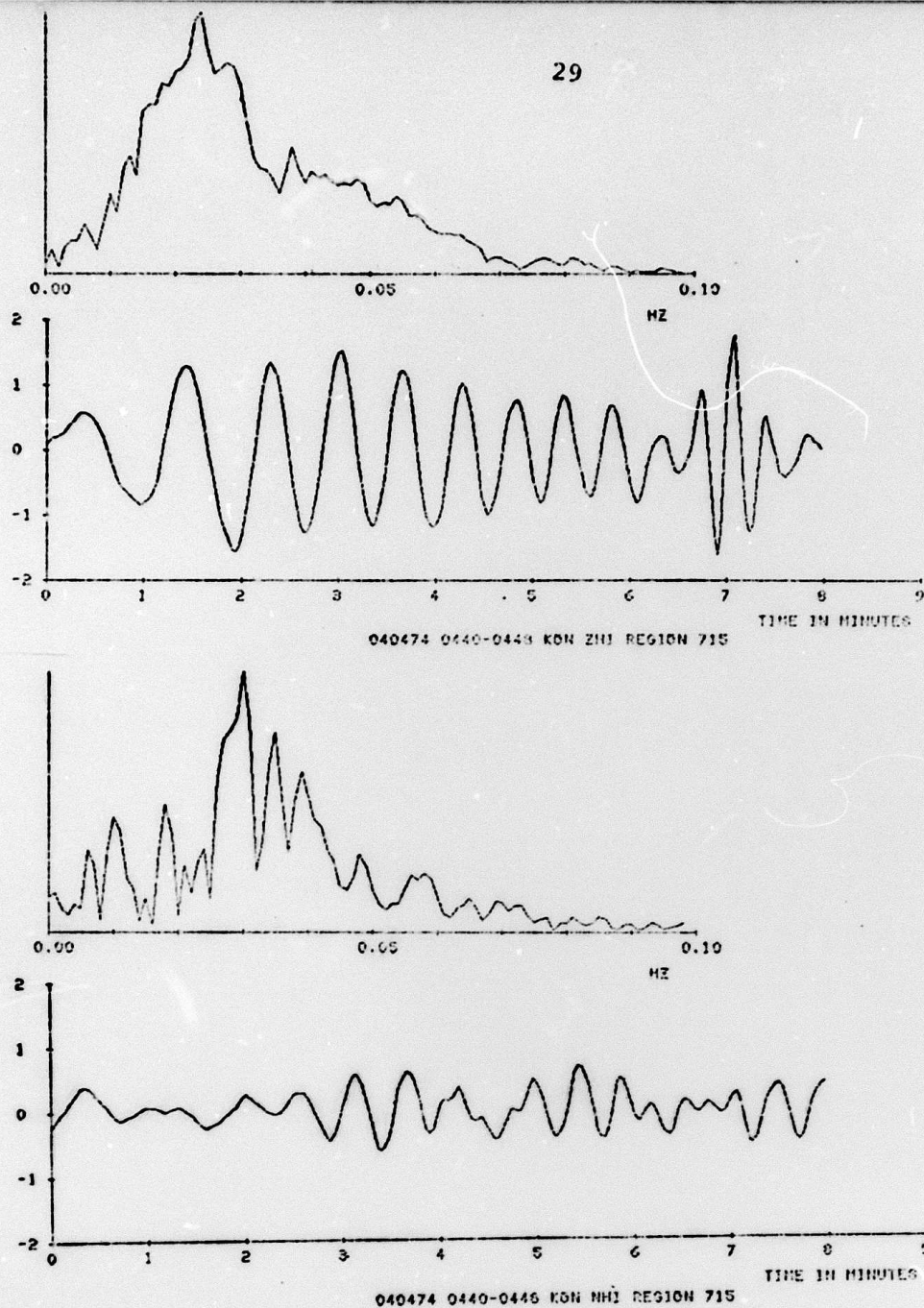


Fig. 8. Kongsberg recordings and amplitude spectra of Tadzhik event 4 April 74, 04:20:01.8. $m_b = 5.1$, depth = 21 km, azimuth = 89.5° , distance = 43.4° . ZHI component top, NHI bottom.

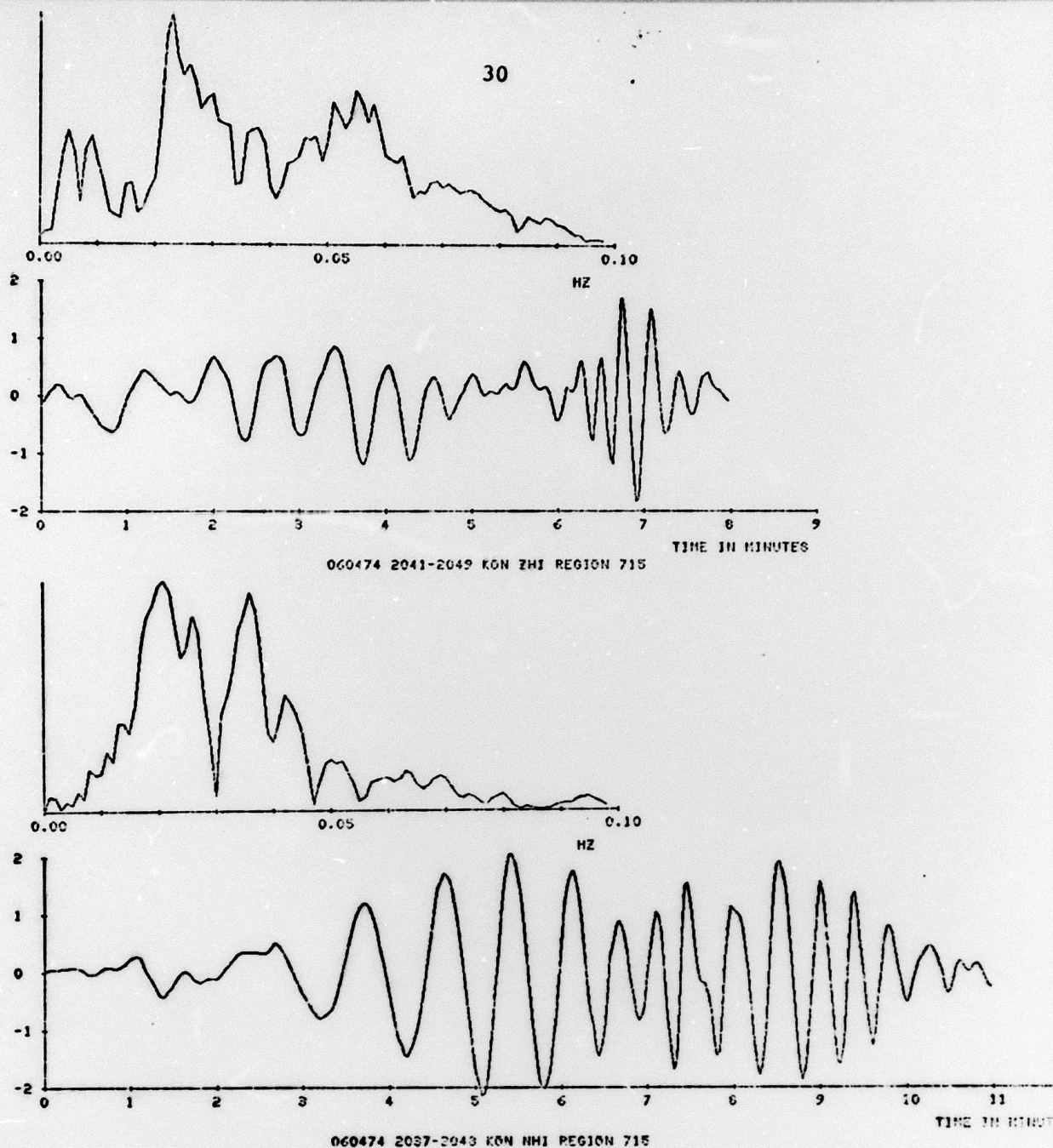


Fig. 9. Kongsberg recordings and amplitude spectra of Tadzhik event 6 April 74, 20:19:36.9. $m_b = 5.2$, depth = 84 km, azimuth = 90.8° , distance = 45.4° . ZHI component top, NHI bottom.

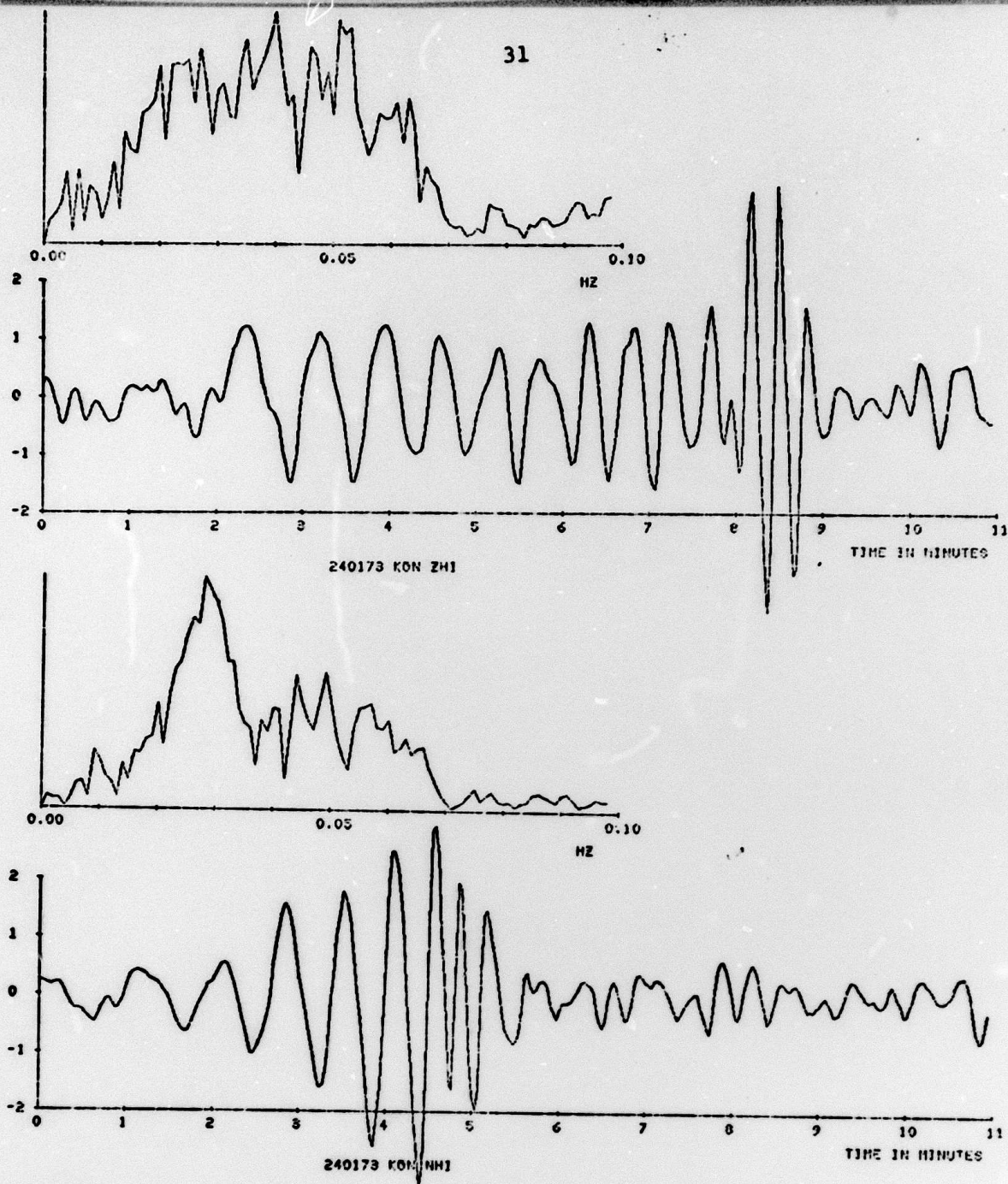


Fig. 10. Kongsberg recordings and amplitude spectra of Southern Sinkiang event 24 January 73, 03:20:20.2. $m_b = 5.1$, depth = 33 km, azimuth = 79.3° , distance = 47.3° . ZHI component top, NHI bottom.

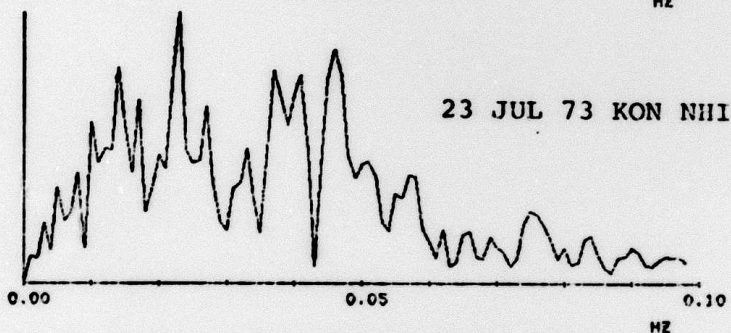
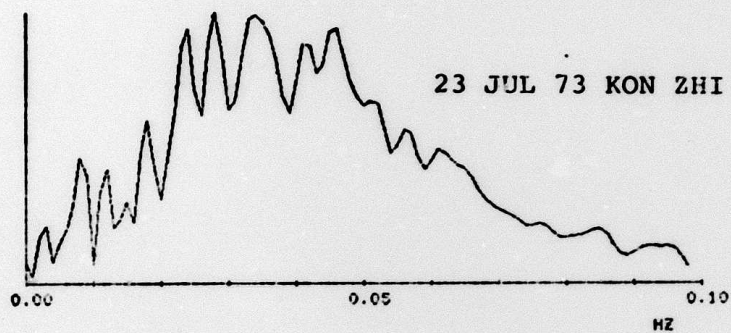
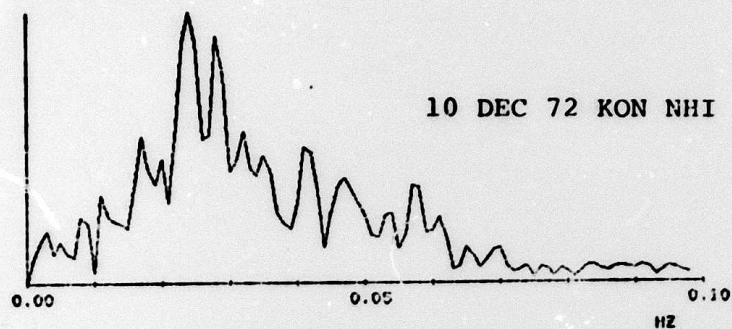
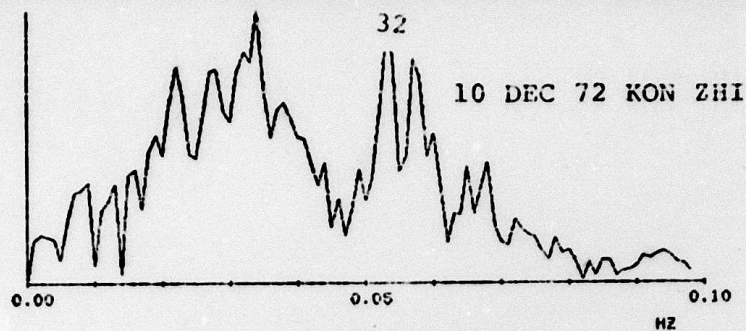


Fig. 11. Amplitude spectra of Kongsberg ZHI and NHI recordings of Eastern Kazakh explosions 10 December 72, 04:27:08.4 (top) and 23 July 73, 01:22:57.8 (bottom).

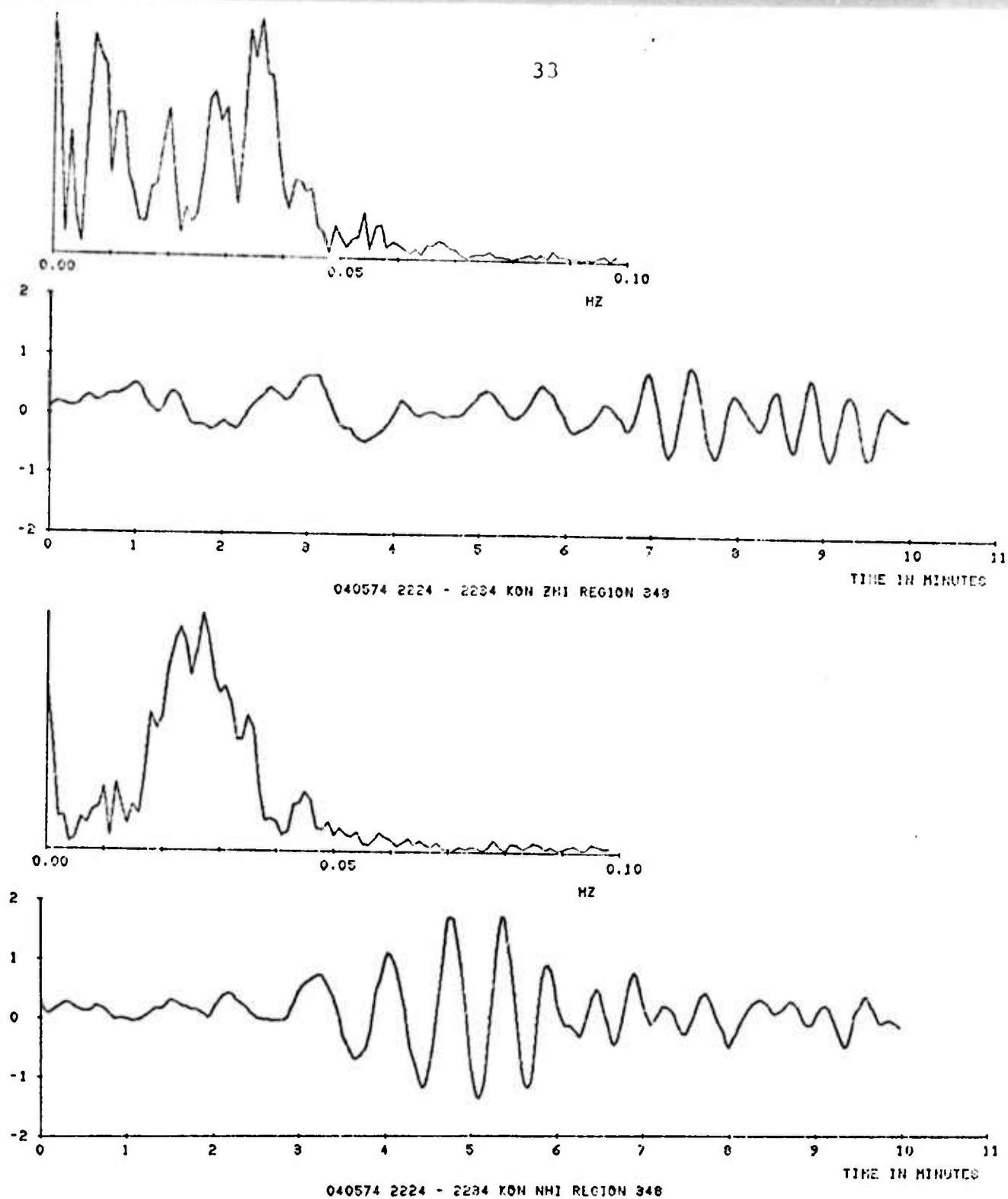


Fig. 12. Kongsberg recordings and amplitude spectra of Iran event 4 May 74, 22:08:24.5. $m_b = 4.5$, depth = 46 km, azimuth = 117.2° , distance = 38.9° . ZHI component top, NHI bottom.

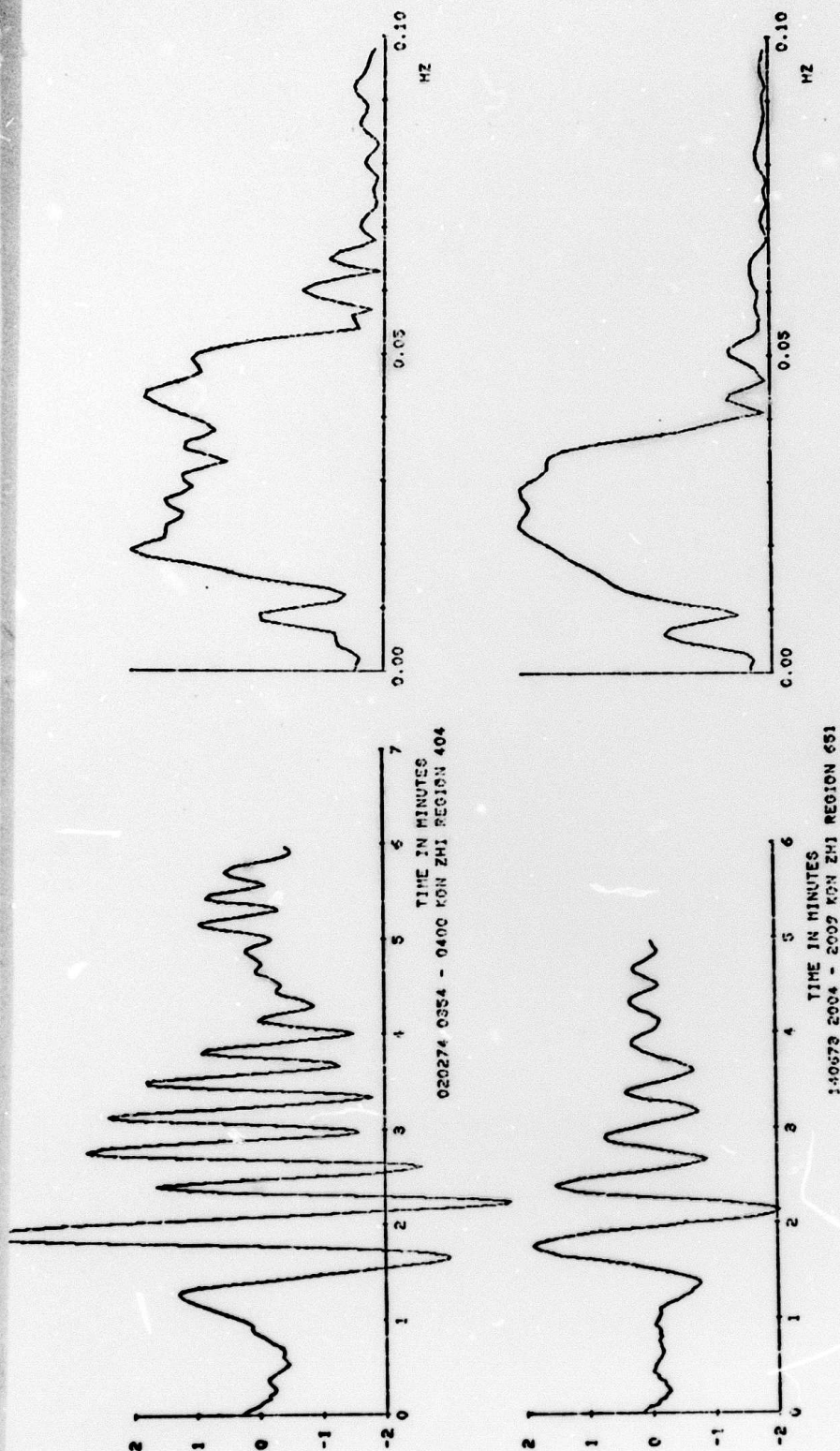


Fig. 13. Kongsberg ZHI recordings and amplitude spectra of event from Azores Islands region 2 February 74, 03:37:25.0 (left) and event from North of Severnaya Zemlya 14 June 73, 19:49:38.5 (right).

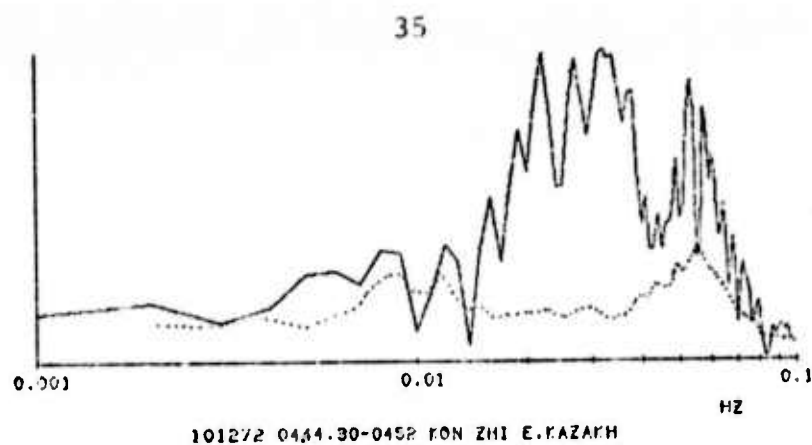


Fig. 14. Kongsberg ZHI power spectrum of the 10 December 1972 Kazakh explosion (solid line) compared with the average noise power spectrum for the time period 5/12-72 - 6/1-73.

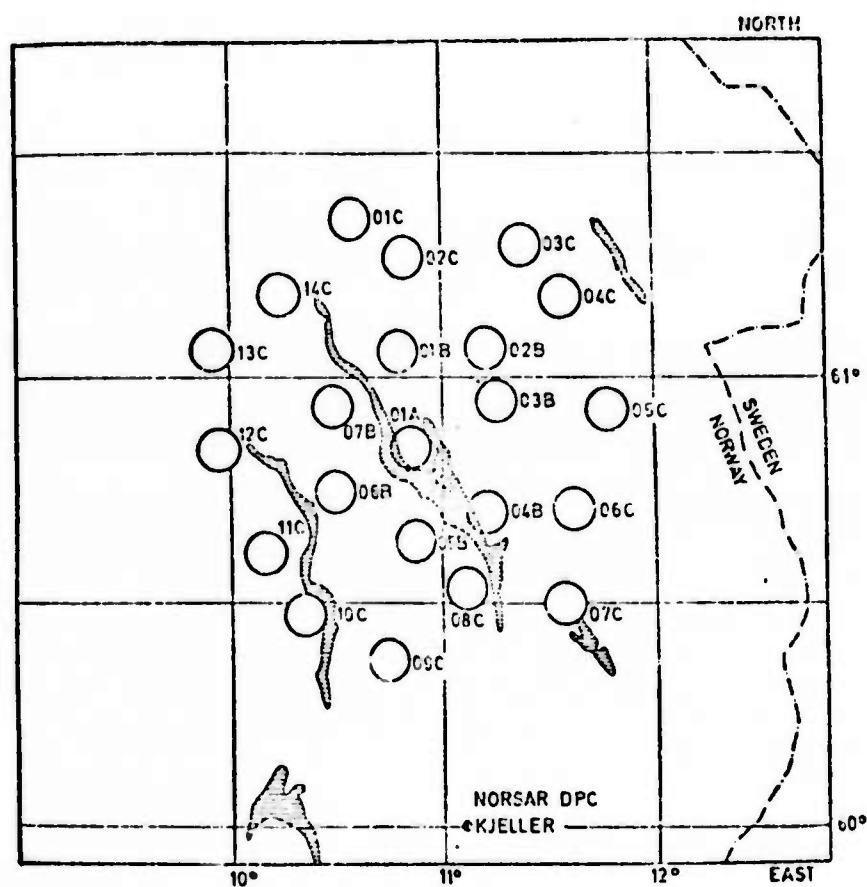


Fig. 15. NORSAR Array Configuration.

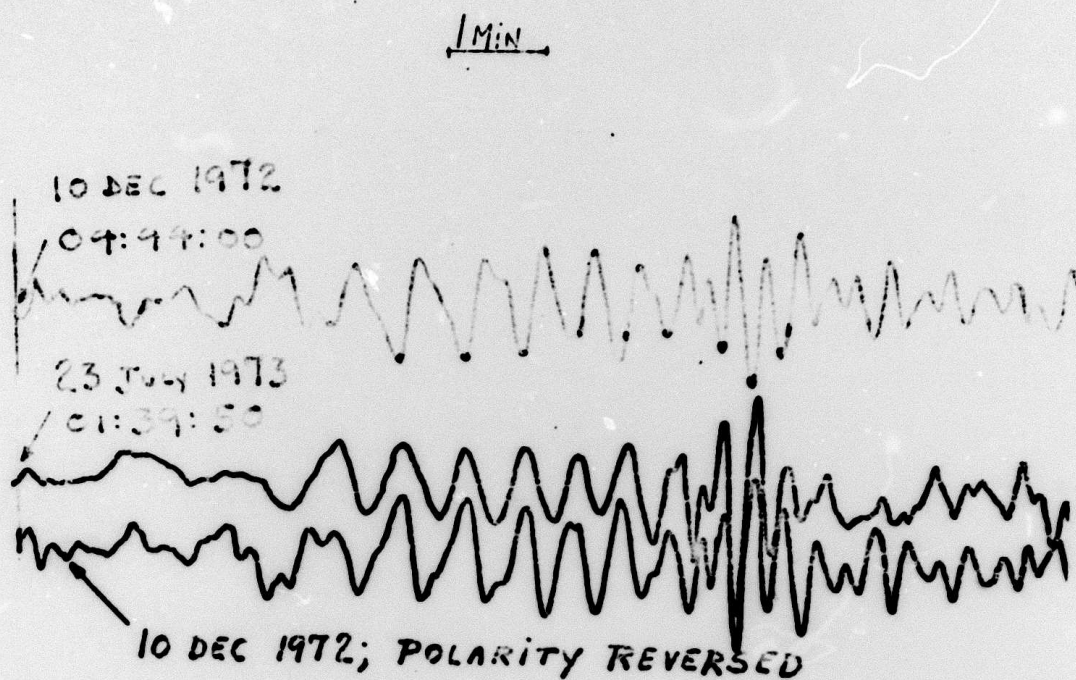


Fig. 16. The upper two traces show the Kongsberg LPz-High gain recordings of the Kazakh events 10 Dec. 1972 and 23 July 1973 respectively. When the traces are lined up at the points of time where they should coincide according to the NOAA epicentral coordinates and origin times they turn out to be about 180° out of phase. Note the good fit throughout the wave trains when the upper recording is flipped over (bottom).

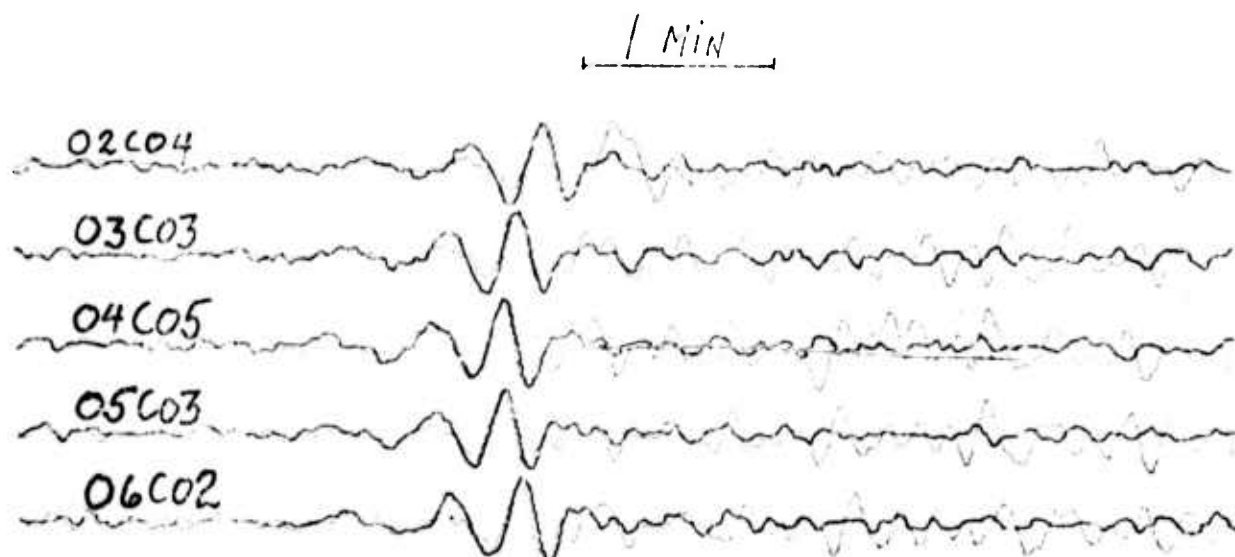


Fig. 17. The NOR SAR LPN-recordings from the Kazakh events and the same instruments put on top of each other. The heavy lines represent the event of 10 Dec. 1972. We notice that there is a very good fit between the Love wave trains when they are put on top of each other at the expected times of arrivals, contrasting with what is found for the corresponding Rayleigh wave trains (Fig. 19). Cfr. Fig. 15 for identification of the instruments used.

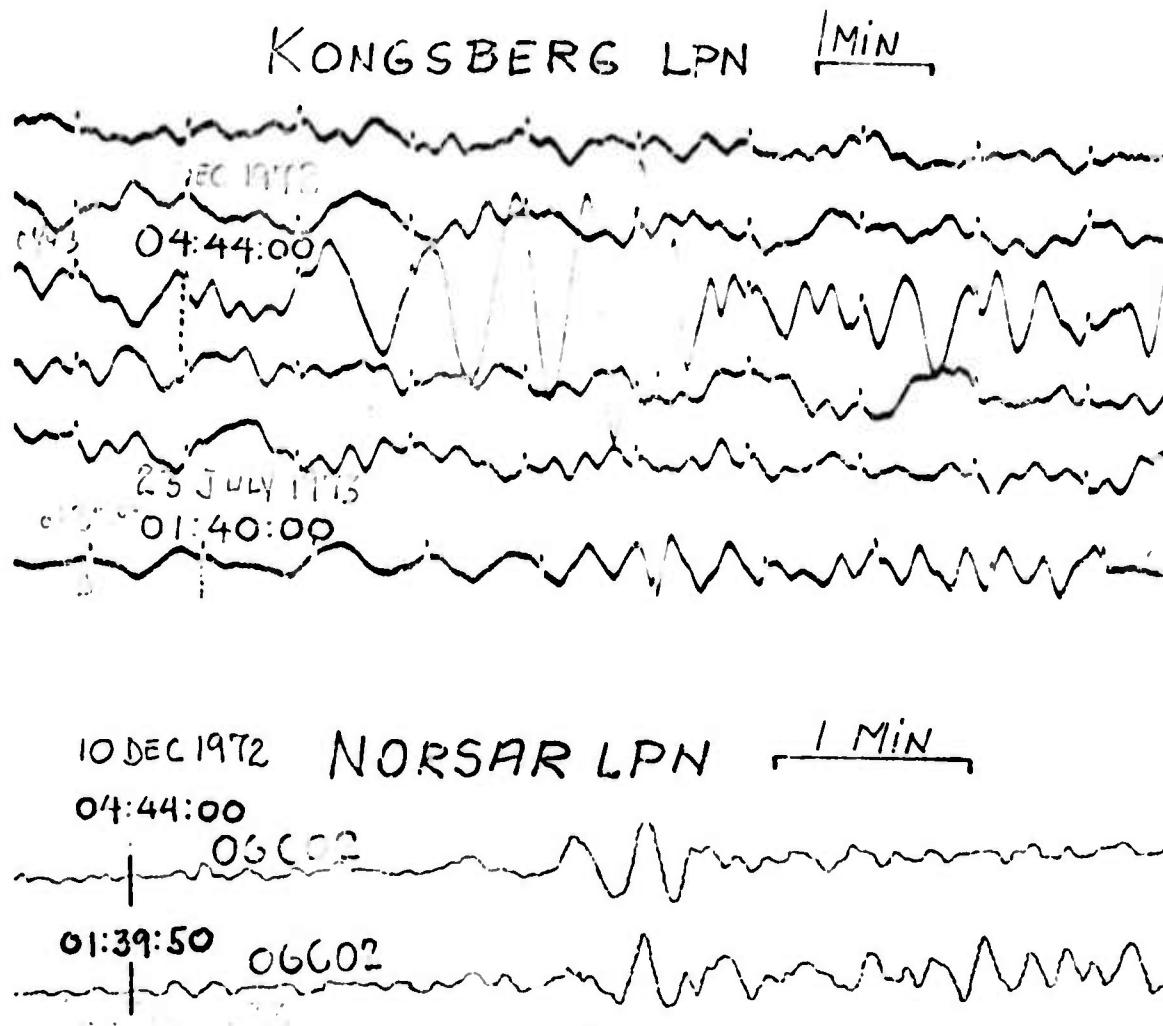


Fig. 18. Comparison of the Kongsberg LPN high gain and one of the NORSAR LPN-recordings of the Love wave trains of the 10 Dec. 1972 event and of the 23 July 1973 event.

Note the much stronger excitation of long period Love waves of the 1972 event. Also note the complexity in the coda of the 1973 event.

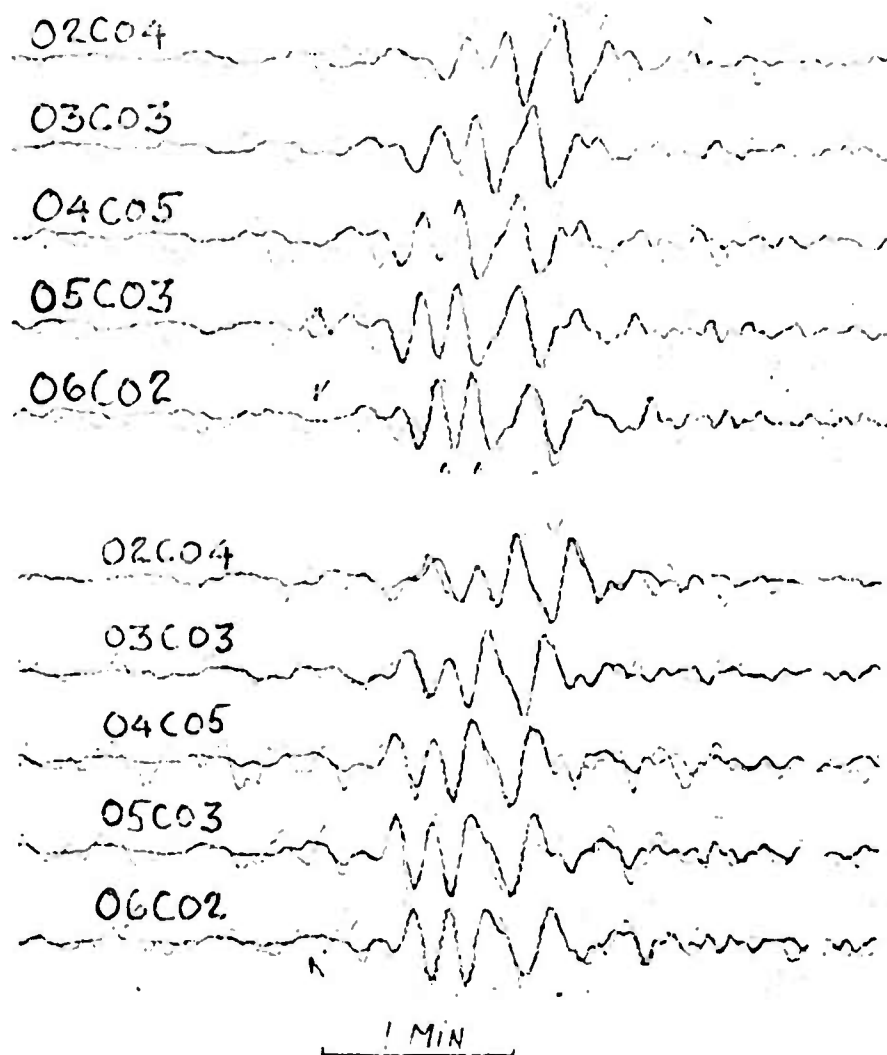


Fig. 19. A comparison of some of the NOR SAR LPZ-recordings from the Kazakh explosions on 10 Dec. 1972 04:27:08.4 and 23 July 1973 01:22:57.8. On the top figure the corresponding recordings at LP-sites 02C04, 03C03, 04C05, 05C03 and 06C02 from the two explosions have been put on top of each other, after adjusting to common expected arrival time. The heaviest line represents the 1973 event. On the lower figure each trace of the July 1973 explosion has been reversed in polarity and adjusted along the time axis to get the best fit.

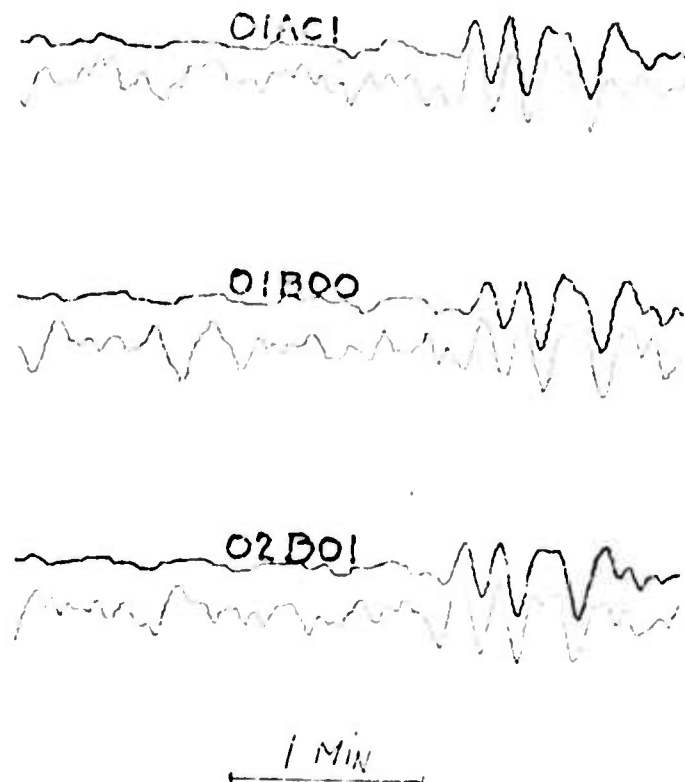


Fig. 20. The NORSAR LPEW-recordings from sites 01A01, 01B00 and 02B01 of the Kazakh explosion 10 December 1972 together with the amplitude reversed version of the 23 July 1973 event. The corresponding traces have been slightly displaced in order to compare the details in the wave trains.

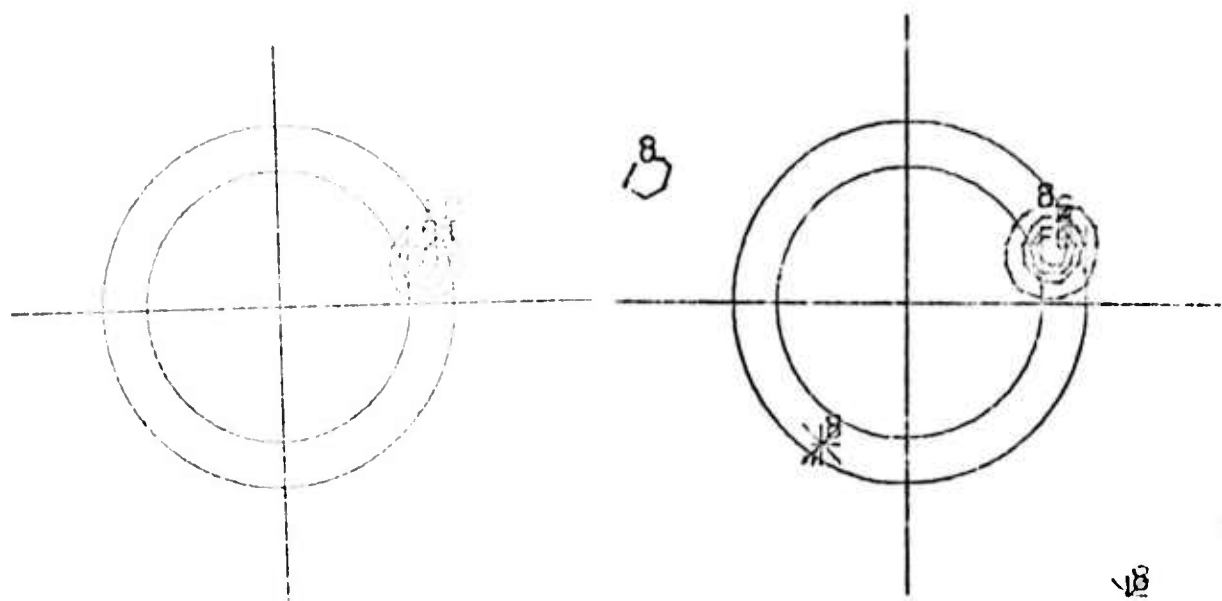


Fig. 21. High resolution wave number spectra at frequency 0.07 Hz from the NS-components of the NORSAR long period array, 23 July 1973 01:42:00 (left) and 01:45:00. The circles represent velocities of 4 (inner ring) and 3 km/s.